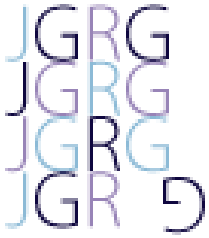
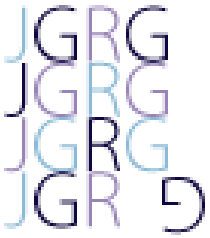


Hajime Sotani, JGRG 22(2012)111407

"Shear oscillations in hadron-quark mixed phase"



RESCEU SYMPOSIUM ON

GENERAL RELATIVITY AND GRAVITATION

JGRG 22

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Shear Oscillations in Hadron-Quark Mixed Phase

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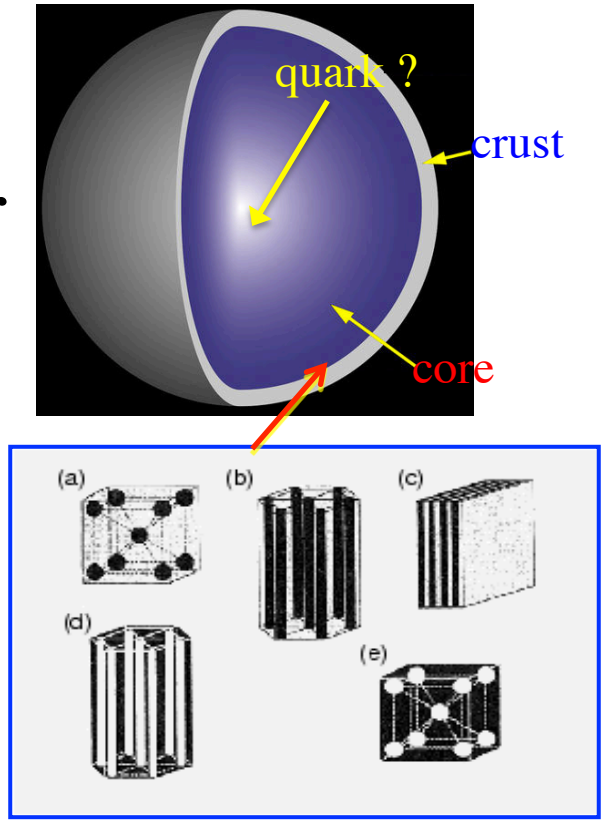
Hadron-Quark Mixed Phase

- Nonuniform structure between the crust and core (pasta).
- As increasing the density, hadronic matter could change to quark matter with the *phase transition*.
- Similar to the pasta in crust region, the hadron-quark mixed phase may become nonuniform structure, whose properties depend strongly on the surface tension.
  - 10 MeV fm^{-2} < σ < 70 MeV fm^{-2}
- *How can we see such properties ??*



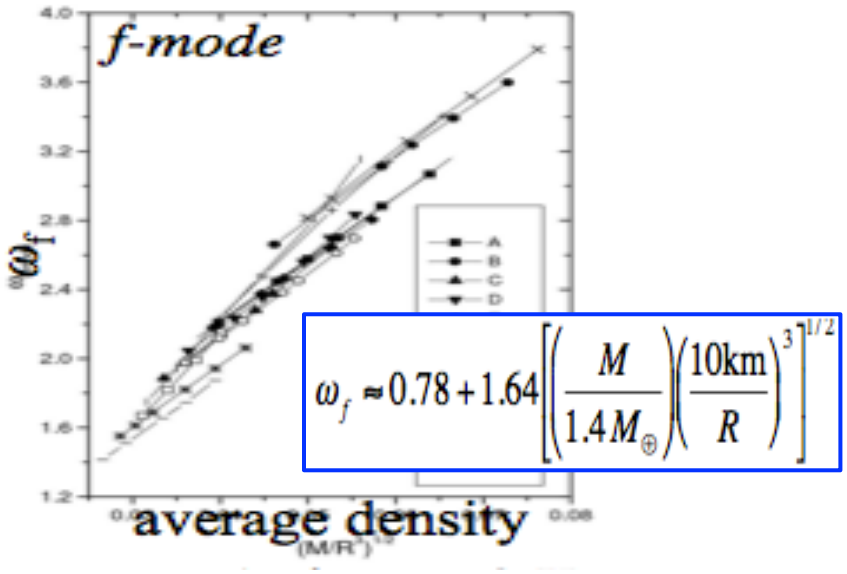
Asteroseismology

- Via the observations of stellar oscillations

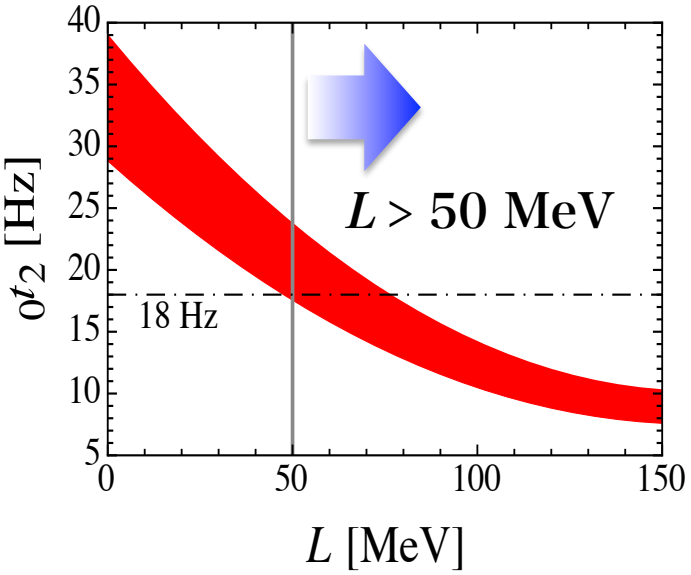
  → One can get the interior information (**asteroseismology**)

  e.g., helioseismology for Sun

- With this technique, the possibilities to get the information of NSs have been suggested.

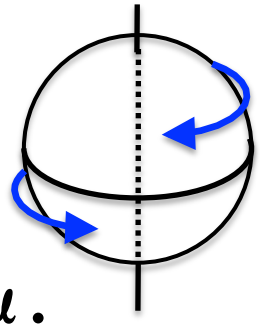


Andersson & Kokkotas (1998)

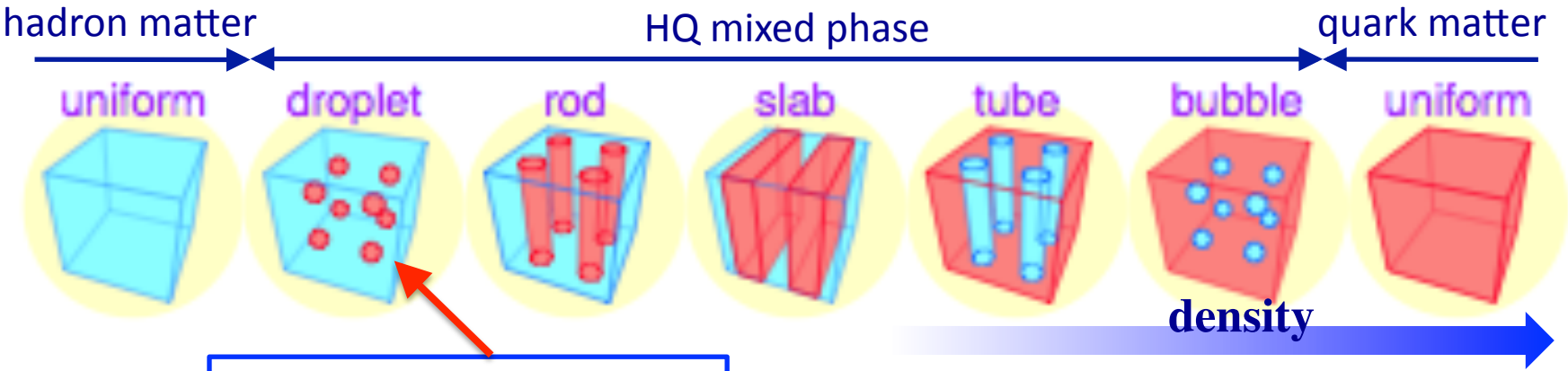


HS+2012

Shear Oscillations



- Shear oscillations can be characterized by μ.
- We know the formula of μ only in bcc lattice.
  - considering the shear only in quark spherical droplet.
  - frequency of fundamental oscillation $\propto v_s$ ($v_s^2 \sim \mu/\rho$)
  - calculated frequencies could be lower limit



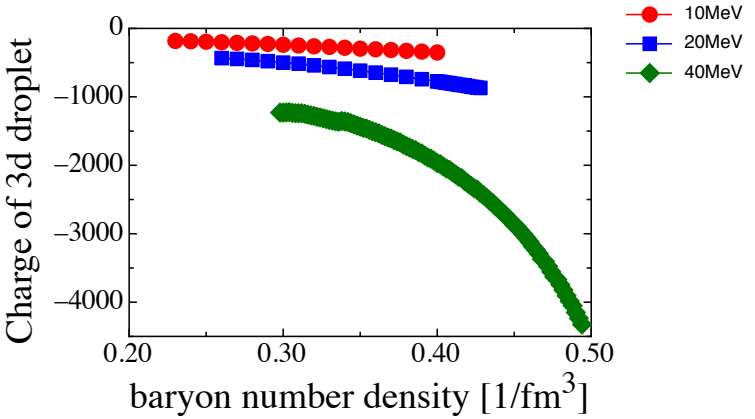
$$\mu = 0.1194 \frac{n_i (Ze)^2}{a}$$

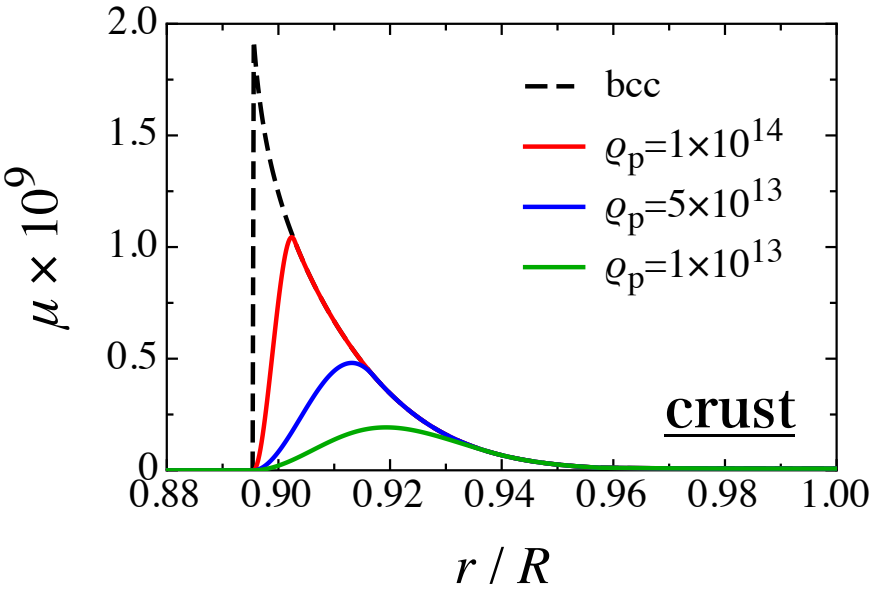
strohmayer et al., 1991

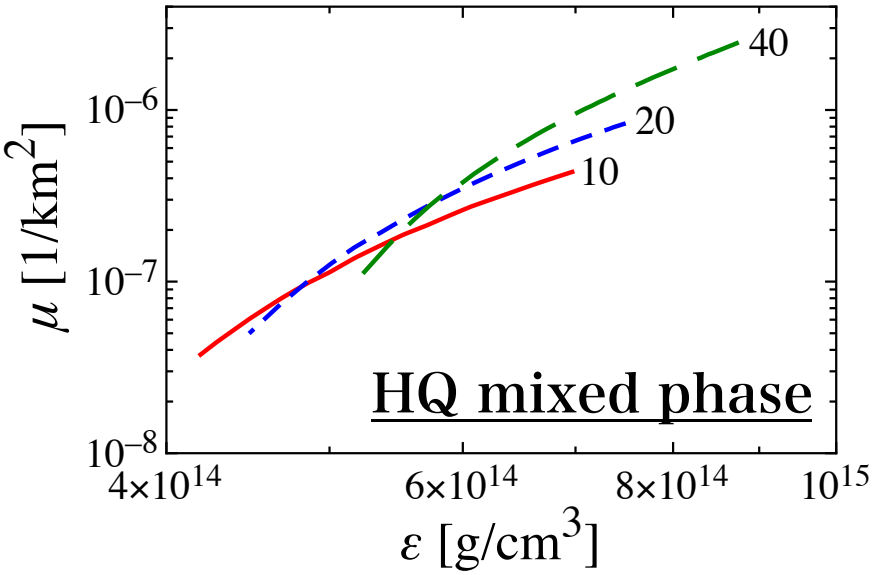
n_i : number density of quark droplet
Z : charge of quark droplet
a : spacing of quark droplet

Shear Modulus

- $\mu \sim 10^{-10}$-10^{-9} in crust
- $\mu \sim 10^{-7}$-10^{-6} in HQ mixed phase
  - number of "charge" is quite different





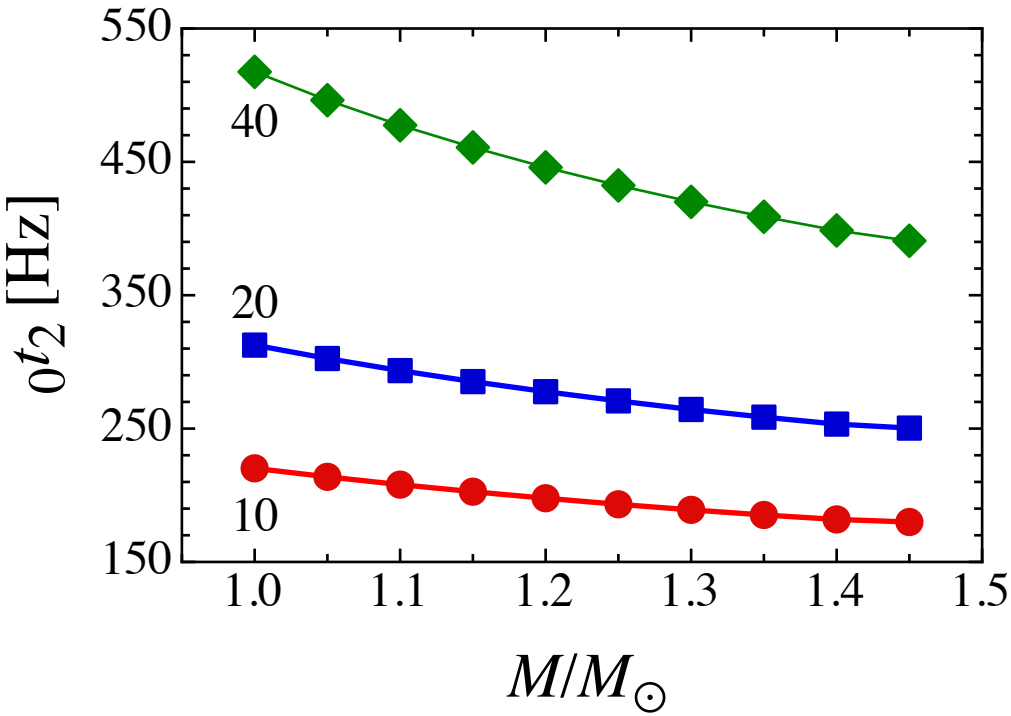


Estimations

- Compared with crust properties,
  - μ becomes ~10^3 times larger
  - ρ becomes ~10 times larger
  - $v_s = (\mu/\rho)^{1/2}$ could be ~10 times larger
- Frequencies of shear oscillations $\propto v_s$
  - In HQ mixed phase, the frequencies of shear oscillations could become ~10 times larger than that in crust.

Fundamental Oscillations 1

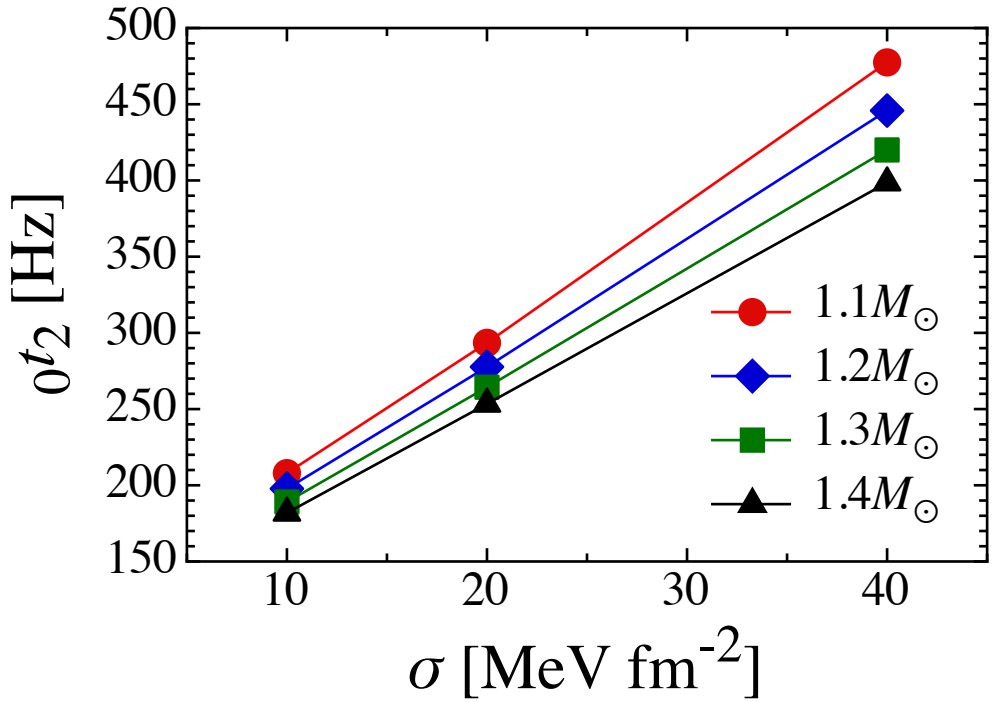
- Frequencies of fundamental shear oscillations as a function of stellar mass
  - those depend strongly on the surface tension



c.f.) $_0t_2$ in crust ~ 20 - 30 Hz

Fundamental Oscillations 2

- We find that the frequencies of fundamental shear oscillations are almost proportional to σ.
- With the help of the observation of stellar mass, it might be possible to obtain the value of σ.



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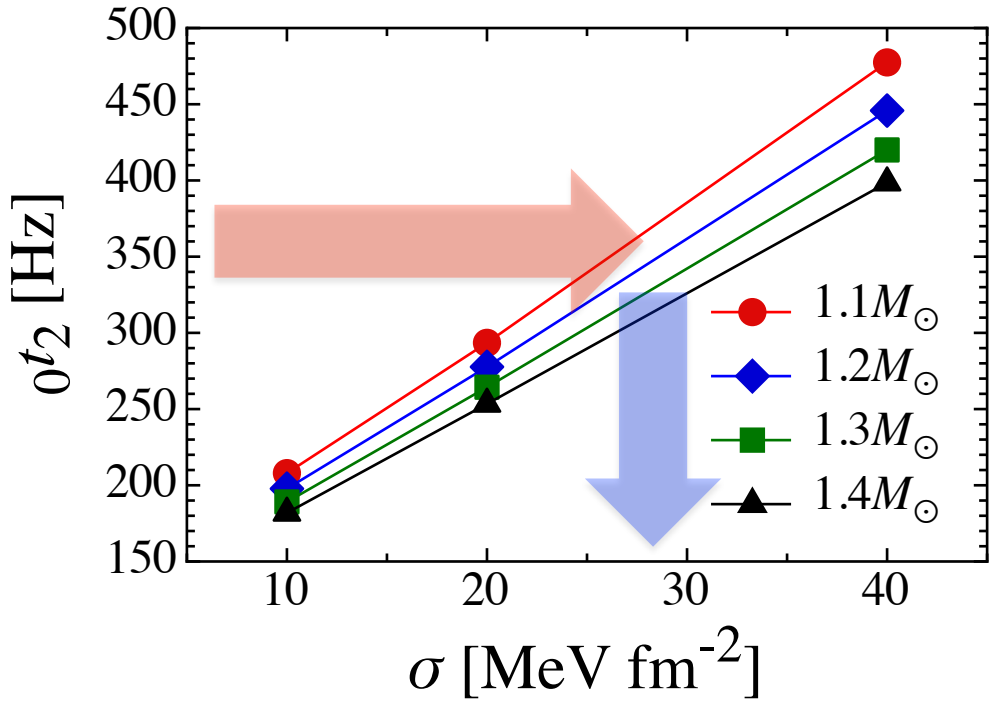
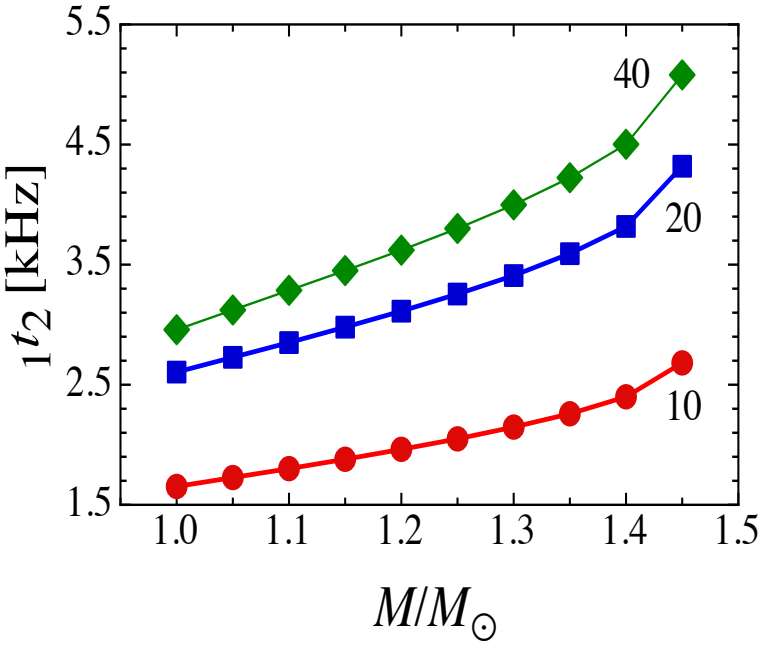


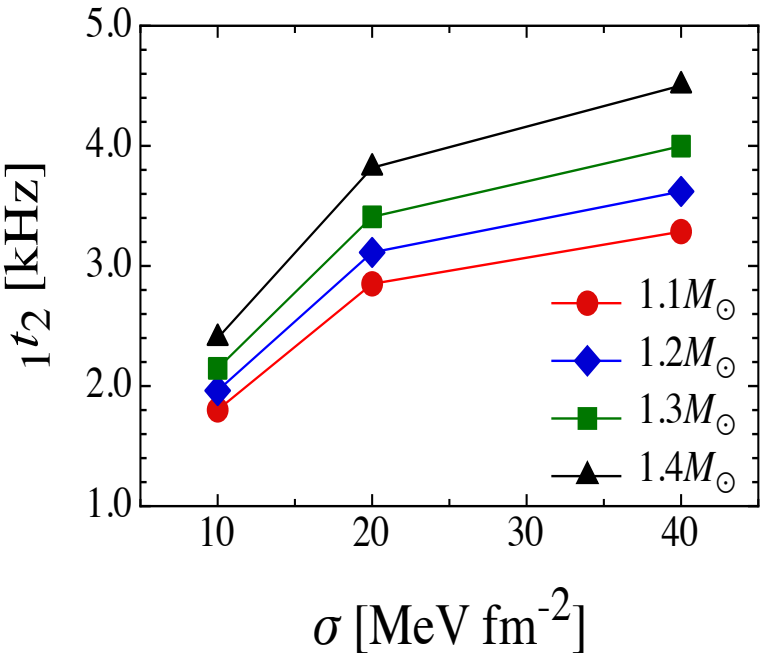
Conclusion

- We consider the shear oscillations in hadron-quark mixed phase, whose properties depends strongly on the surface tension.
- Frequencies of shear oscillations in HQ phase becomes ~10 times larger than those in crust.
- Frequencies of fundamental oscillations are proportional to surface tension.
- We show the possibility to determine the value of σ.
  - With the help of the observation of stellar mass, one might be possible to obtain the value of σ via the observation of shear oscillations.

1st Overtones

- Frequencies of 1st overtone shear oscillation as a function of stellar mass
- We can not see the linearity with respect to σ.

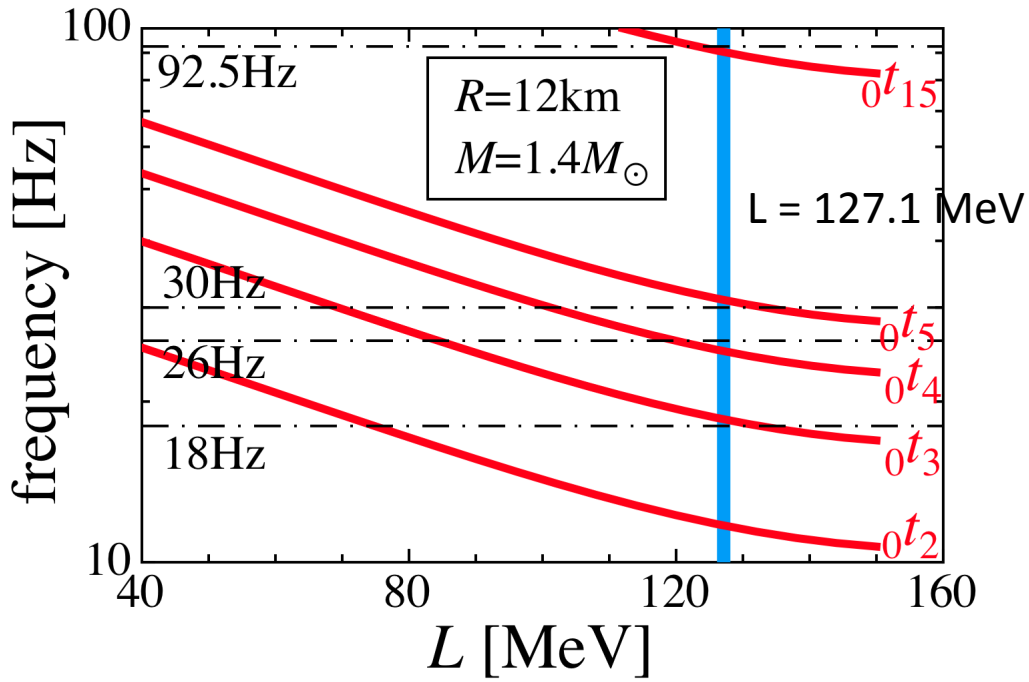




Comparison with QPO frequencies

HS+(2012b)

- Comparison of frequencies of torsional oscillations with the QPO frequencies observed in SGR 1806-20



- less than 5% accuracy